Verification of AL800 Garnet Material Properties Using a Test Cavity

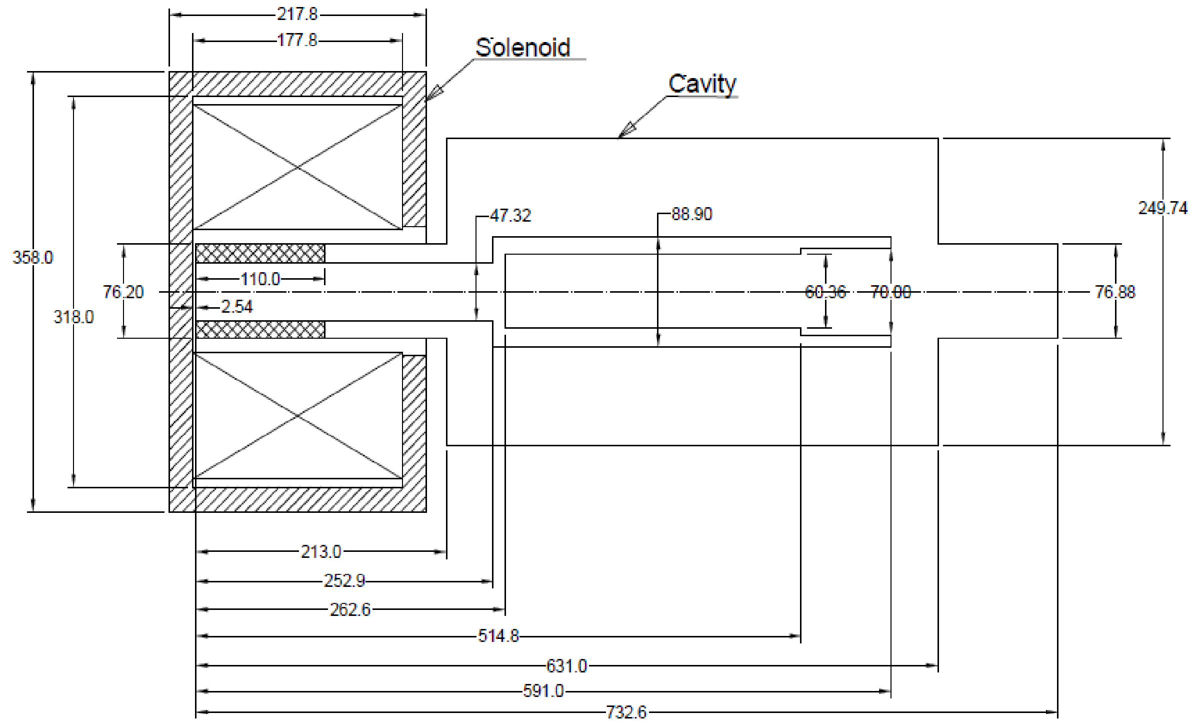
References:

1. G. Romanov, et al, "Perpendicular Biased Ferrite Tuned Cavities for the Fermilab Booster", FNAL publication Fermilab-CONF-14-125-TD
2. R. Madrak, et al, "Static Permeability of AL-800 Garnet Material", FNAL TD note TD-15-004, April 2015.
3. R. Madrak, et al, "Loss Tangent of AL-800 Garnet Material", FNAL TD note TD-15-005, June 2015.
4. R. Madrak, et al, "Permeability of AL-800 Garnet Material", FNAL TD note TD-15-014, July 2015.
5. V. Kashikhin, "Solenoid for the NOvA RF Cavity Tuner", May 09, 2012, technical note.

D. M. Poser, Microwave Engineering, Wiley & Son, Inc., 1998, ch. 9.

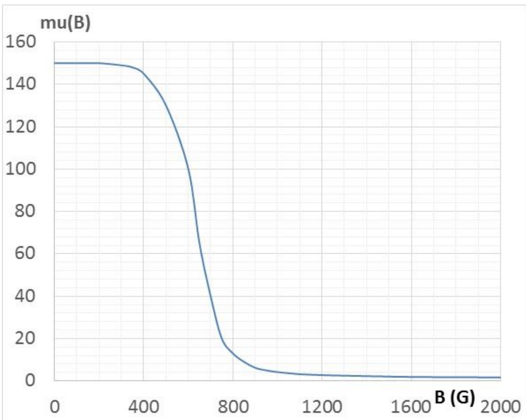
Test Cavity: Geometry

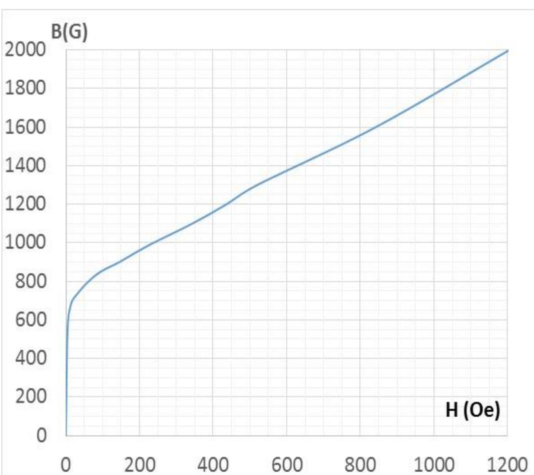
x (mm)	y (mm)
0.0	23.66
0.0	38.10
213.0	38.10
213.0	124.87
631.0	124.87
631.0	38.44
732.6	38.44
732.6	0.00
262.6	0.00
262.6	30.18
514.8	30.18
514.8	35.00
591.0	35.00
591.0	44.45
252.9	44.45
252.9	23.66
0.0	23.66



Initially Assumed Material Properties

Static Magnetic Properties





RF Properties

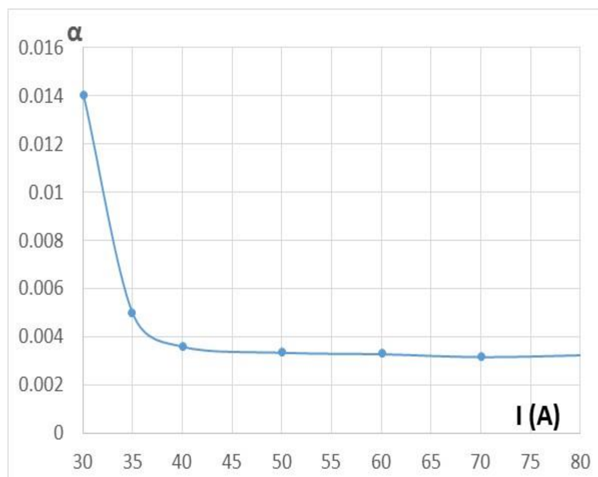
$$\mu' = 1 + \frac{\omega_0\omega_m(\omega_0^2 - \omega^2) + \omega_0\omega_m\omega^2\alpha^2}{[\omega_0^2 - \omega^2(1+\alpha^2)]^2 + 4\omega^2\omega_0^2\alpha^2}$$

$$\mu'' = \frac{\alpha\omega\omega_m[\omega_0^2 + \omega^2(1+\alpha^2)]}{[\omega_0^2 - \omega^2(1+\alpha^2)]^2 + 4\omega^2\omega_0^2\alpha^2}$$

$\boldsymbol{\omega_0 = \mu_0\gamma \cdot H_0}$,
$\boldsymbol{\gamma = e/m_e}$ = $1.76 \cdot 10^{11}$ C/kg
$\boldsymbol{\omega_m = \mu_0\gamma \cdot M_s}$

$\boldsymbol{\alpha = \mu_0\gamma/2\omega \cdot \Delta H = 10^{-7}\gamma/f_0 \cdot \Delta H}$

ΔH is the half-width of the gyro-magnetic resonance curve at f = 9.4 GHz



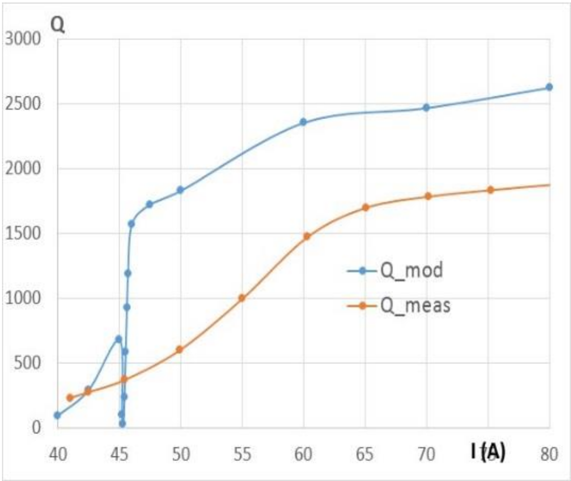
$\boldsymbol{\alpha}$ = 0.0035 → $\boldsymbol{\Delta H}$ = 23.3 Oe,
Vendor's data : $\boldsymbol{\Delta H}$ = 24.0 Oe.

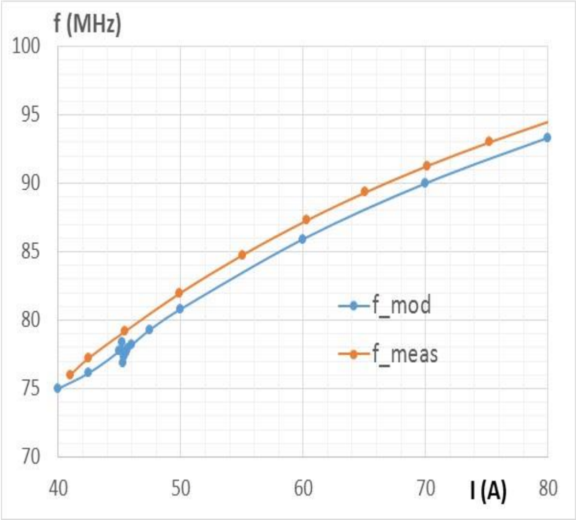
H_{gm} (Oe) = f (MHz)/2.8

75 MHz → 26.8 Oe

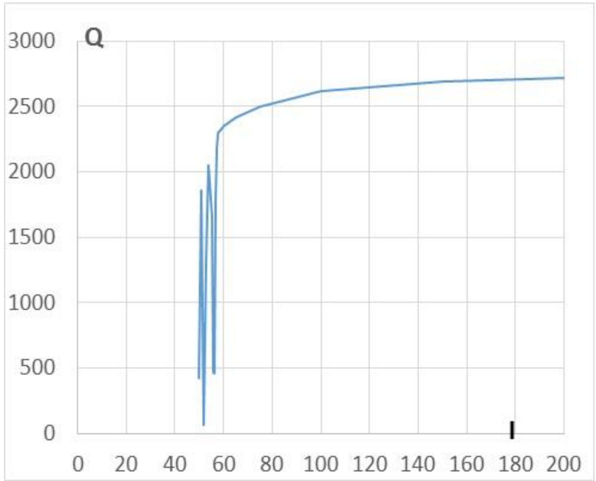
Importance of Fine Meshing

Fist try: "fine" mesh and linear flux return

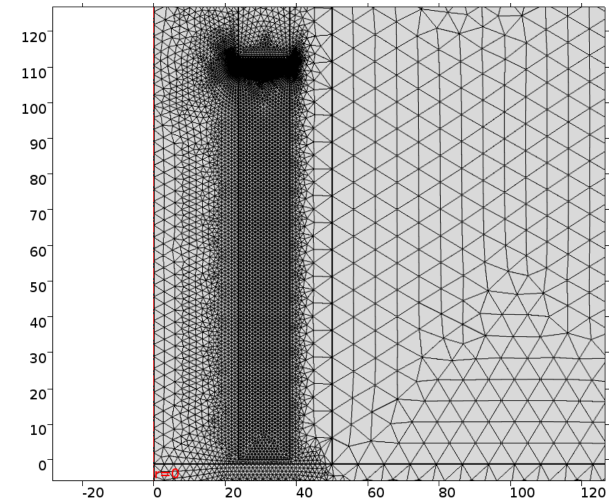


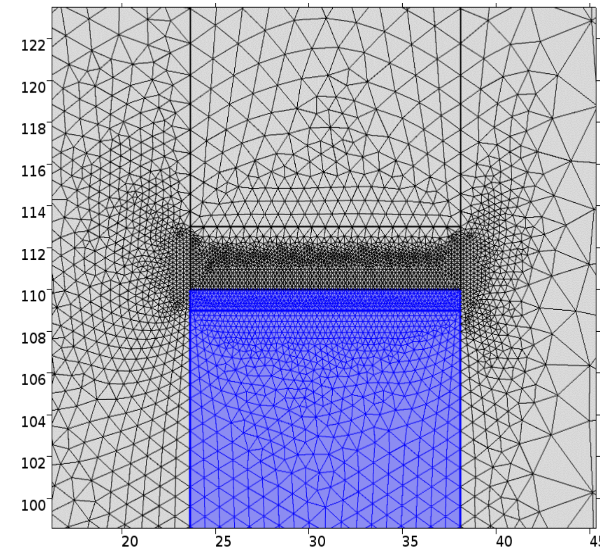


"Extra-fine" mesh and non-linear flux return

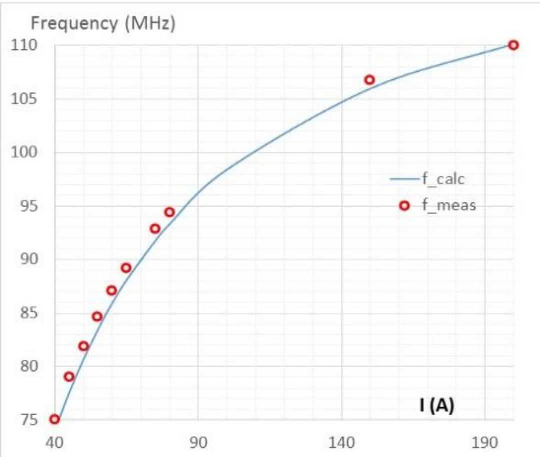


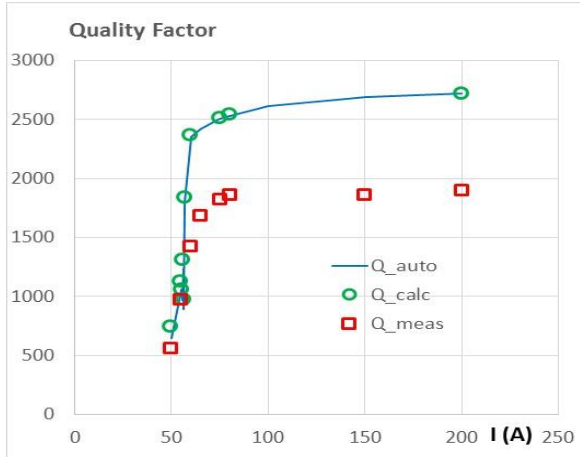
Locally enhanced mesh

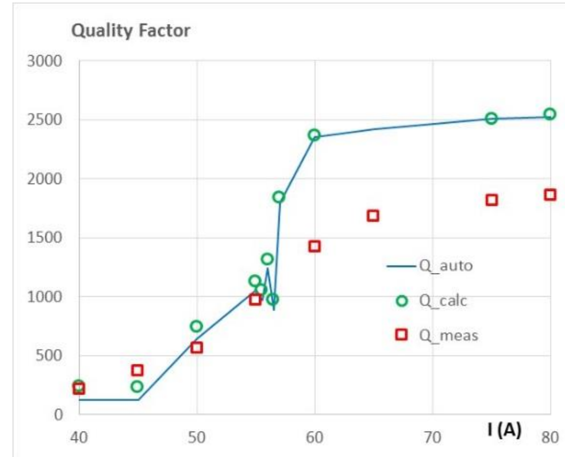




Results with the “old” material







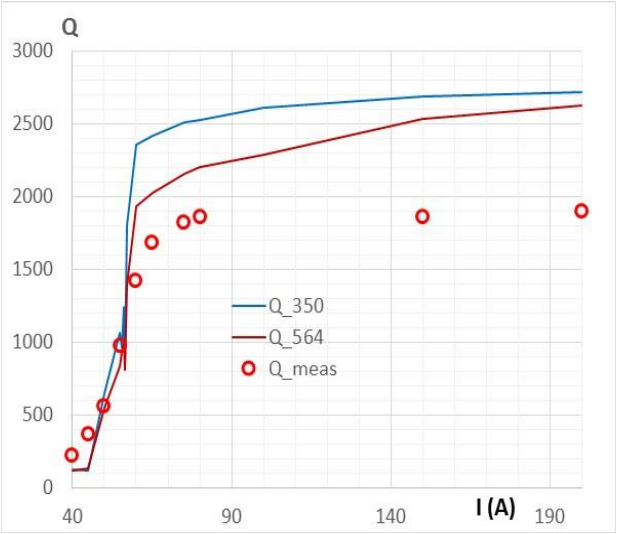
Problem! - calculated Q is significantly higher than what the measurements show.

Can the difference in the material properties be the reason?

	Material in [3]	Material in the Test cavity
Dielectric permittivity ε	13.86	13.80
tg (δ_ε)	0.0001	0.0001
$4\pi \cdot Ms$ (Oe)	764	795
-3 dB L.W. (Oe)	24	37.6

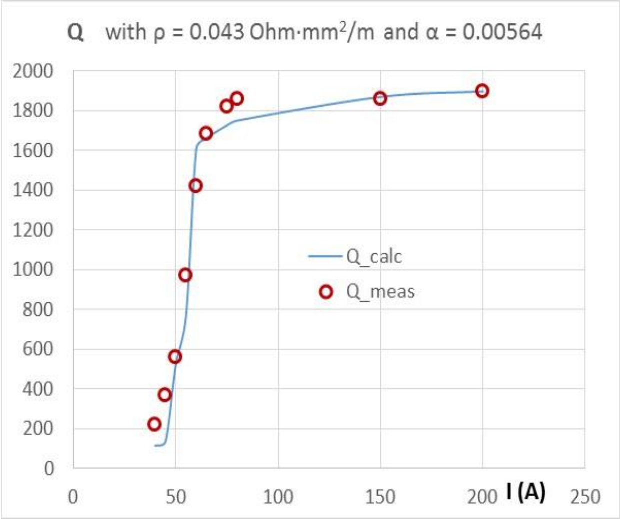
Search for an explanation of the difference

1. Updated material properties:
α = 0.00564



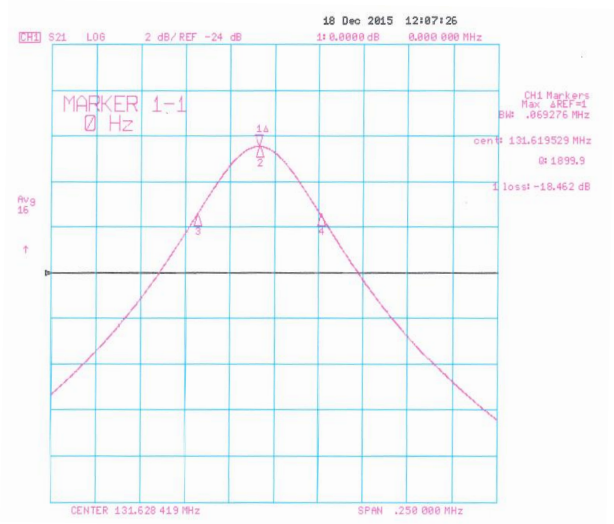
Improvement in the vicinity of the g/m resonance

2. Assumed higher resistivity of the wall material



Results look good, but unrealistic as the material just cannot be so bad

3. Check of the quality factor of the cavity without ferrite

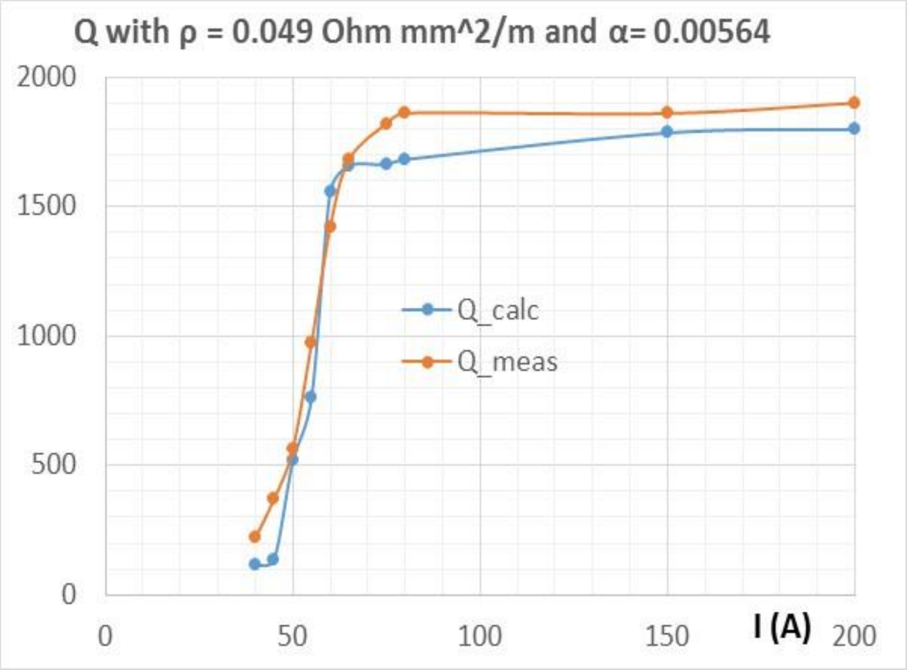


Q = 1900 ???

It is even worse than imagined in i.2 of this slide: Q = 2675

Radiation is the reason of the observed Q values

Further investigation provided the explanation of why the quality factor is so low: poor mechanical contact between different parts of the cavity led to RF leakage. Some measures to mitigate the leakage resulted in the maximum measured value of the quality factor of ~**2500**. Effective resistivity of material that explains the maximum measured quality factor of the bare cavity is **$4.88 \cdot 10^{-8}$ Ohm-m** (conductivity **σ = 2.05E7 Sim/m**).



Summary

To verify the accuracy of the modeling a tunable transversely-biased ferrite-loaded RF cavity using method and technique developed in [4], RF measurements were made using specially designed test RF cavity in the range of bias currents that resulted in the resonance frequency change between 75 MHz and 110 MHz. The measurement data was compared with predictions of the modeling. It was found that quality of the test cavity fabrication can distort the quality factor data obtained by the measurements because of significant radiation due to the poor mechanical contact between the current-carrying parts of the cavity. After this radiation is taken into account, the measurement data becomes consistent with the prediction of the modeling.

Using wrong set of data representing the properties of the garnet material can also lead to disagreement between the measured and calculated properties of the cavity. Comparison of samples of the material procured at different times show that one can expect significant difference in the Line Width parameter that directly affects reachable quality factor and hence RF loss in the material. A way must be suggested on how the quality of the AL-800 garnet material could be guaranteed and/or checked before the assembly of the cavity is attempted.